Opportunities and challenges in PV performance analytics: a case study in module soiling

Michael G. Deceglie\textsuperscript{1}  
Leonardo Micheli\textsuperscript{1,2}  
Matthew Muller\textsuperscript{1}

\textsuperscript{1}National Renewable Energy Laboratory  
\textsuperscript{2}Colorado School of Mines
PV data varies in quality and detail

- **Sources:**
  - Public data sets
  - Research systems
  - Fleet data (asset owners / module manufacturers)

maps.nrel.gov/pvdaq
Comparison of two systems

System 1: Research system at NREL

Maps.nrel.gov/pvdaq
Comparison of two systems

System 2: Elementary School in Connecticut

Edna C. Stevens Elementary School

Analytics [Wed May 17, 2017]

Total Energy generated by Inverter 1 [100303-27 PVI 82kW - 208 VAC] = 406.9 kWh
Total Energy generated by Inverter 2 [100303-29 PVI 82kW - 208 VAC] = 446.3 kWh

www.solrenview.com/SolrenView/mainFr.php?siteId=726
## Comparison of two systems

### Research system
- **Metadata:**
  - Location
  - System orientation
  - Module details
  - Inverter details
- **Time series:**
  - 1-minute
  - AC power/current/voltage
  - DC power/current/voltage
  - Ambient temperature
  - Inverter temperature
  - 3 module temperatures
  - Plane-of-array irradiance
  - DAS diagnostics

### Elementary school
- **Metadata:**
  - Location
  - Module details
  - Inverter details
- **Time series:**
  - 5-minute
  - AC power/current/voltage
  - DC voltage
## Comparison of two systems

<table>
<thead>
<tr>
<th>Research system</th>
<th>Elementary school</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Metadata:</strong></td>
<td><strong>Metadata:</strong></td>
</tr>
<tr>
<td>o Location</td>
<td>o Location</td>
</tr>
<tr>
<td>o System orientation</td>
<td>o Module details</td>
</tr>
</tbody>
</table>

**Challenge:**
Analytics that enable comparisons between data sets from disparate systems.

- AC power/current/voltage
- DC power/current/voltage
- Ambient temperature
- Inverter temperature
- 3 module temperatures
- Plane-of-array irradiance
- DAS diagnostics
Analytics example: Soiling loss

Goal: Use historical PV data to inform planning

• We’re already collecting the data we need, in PV production data
• To unlock the potential:
  o Globally Scalable
  o Statistically rigorous
  o Flexible
Two part calculation

Operational data
Metadata

Model PV System

Performance metric

Extract soiling

Soiling loss
Confidence interval
Two part calculation

Operational data
Metadata

Model PV System

Performance metric

Extract soiling

Soiling loss
Confidence interval

Extraction should handle varying detail/quality in data and model
Performance metric

Operational data
Metadata

Model PV System

Temperature-corrected daily production
Daily insolation

Extract soiling

Soiling loss
Confidence interval
Steps

1. Detect cleaning events
   - This divides data into intervals
2. Fit the slope for each interval
   - Yields a daily soiling derate
   - Also get an uncertainty in each slope
3. Calculate and apply derate to daily insolation
4. Compare raw and derated insolation of period of interest
5. Use slope uncertainties in Monte-Carlo to estimate uncertainty
Step 1: Detect cleaning events

Example subset
Step 1: Detect cleaning events

- Apply rolling median
- Detect upward steps
- **No need for precipitation data**
Step 2: Extract slope for each interval
Step 2: Extract slope for each interval

• Robust slope estimation needed for anomalous data
Step 2: Extract slope for each interval

- Robust slope estimation needed for anomalous data
- Solution: Theil-Sen estimator
  - Consider lines between all pairs, take the median slope
Step 2: Extract slope for each interval

- Robust slope estimation needed for anomalous data
- Solution: Theil-Sen estimator
  - Consider lines between all pairs, take the median slope
Step 3: Derate insolation

- Raw insolation
- Derated insolation
- Daily performance
- Soiling derate
Step 4: Integrate and compare insolation

- Raw insolation
- Derated insolation
- Daily performance
- Soiling derate
Step 5: Monte Carlo for Uncertainty

- Use the confidence interval for the slope
- Recalculate 1000s of randomized derate profiles
- Look at the distribution of integrated losses
Steps

1. Detect cleaning events
   - This divides data into intervals

2. Fit the slope for each interval
   - Yields a daily soiling derate
   - Also get an uncertainty in each slope

3. Calculate and apply derate to daily insolation

4. Compare raw and derated insolation of period of interest

5. Use slope uncertainties in Monte-Carlo to estimate uncertainty
Application: annual variation

We observe substantial year-to-year variations
Annual vs. long-term loss

- Year-to-year variation can be large relative to long term losses
- There may be no such thing as a “typical soiling year”
  - Perhaps we should quantify the worst-case year?
Validation

• Comparison with data from soiling stations show general agreement
• Different assumptions about precipitation and cleaning explain discrepancies
Recommendations for PV analytics

PV field performance data has varying quality and detail

- Decouple the system modeling for the analysis
  - Provides generality and flexibility
  - Minimize the inputs required to the analysis step
- Use methods that are robust to outliers
  - Reduces need for hands-on analysis
- Emphasize confidence intervals

Operational data Metadata → Model PV system → Performance metric → Extract soiling → Soiling loss Confidence interval

Further reading
- “Quantifying Year-to-Year Variations in Solar Panel Soiling from PV Energy-Production Data,” Michael G. Deceglie, Leonardo Micheli, and Matthew Muller, PVSC 2017 (forthcoming)

Acknowledgment
Thank you to Greg Kimball (SunPower), and Sarah Kurtz (NREL) for insightful conversations.
Acknowledgement

• Thank you to Greg Kimball (SunPower), and Sarah Kurtz (NREL) for insightful conversations

• Further reading:
  o “Quantifying Year-to-Year Variations in Solar Panel Soiling from PV Energy-Production Data,” Michael G. Deceglie, Leonardo Micheli, and Matthew Muller, PVSC 2017 (forthcoming)

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC
This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-08GO28308 with the National Renewable Energy Laboratory. Funding provided by U.S. DOE Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Program.